UNCLASSIFIED

| AD NUMBER |
| --- |
| **AD085690** |
| CLASSIFICATION CHANGES |
| TO: **UNCLASSIFIED** |
| FROM: **CONFIDENTIAL** |
| LIMITATION CHANGES |
| TO: **Approved for public release; distribution is unlimited.** |
| FROM: **Distribution authorized to U.S. Gov't. agencies only; Proprietary Information; 26 SEP 1955. Other requests shall be referred to Office of Naval Research, Arlington, VA 22203.** |
| AUTHORITY |
| **30 Sep 1967, DoDD 5200.10; ONR ltr 24 Apr 1974** |

THIS PAGE IS UNCLASSIFIED

UNCLASSIFIED

| AD NUMBER |
| --- |
| **AD085690** |
| CLASSIFICATION CHANGES |
| TO: **CONFIDENTIAL** |
| FROM: **SECRET** |
| AUTHORITY |
| **30 Sep 1958, DoDD 5200.10** |

THIS PAGE IS UNCLASSIFIED

Best
Available
Copy

85690



DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
WASHINGTON, D. C.

26 September 1955
Report No. 982
(Special)
Copy No.

FC

# DEVELOPMENT OF A DEVICE FOR PRESSURE MINE SWEEPING

*Contract Nonr-686(00)*

NOTICE: THIS DOCUMENT CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18, U.S.C., SECTIONS 793 and 794. THE TRANSMISSION OR THE REVELATION OF ITS CONTENTS IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.

26 September 1955

Report No. 982
(Special)

# DEVELOPMENT OF A DEVICE FOR PRESSURE MINE SWEEPING

Contract Nonr-686(00)

Written by:

C. A. Klug

No. of Pages: 39

Approved by:

C A Gongwer

C. A. Gongwer
Manager
Underwater Engine Division

Period Covered:

1 December 1951 through 1 May 1955



AEROJET-GENERAL CORPORATION

Azusa, California

Report No. 982

CONTENTS

## CONTRACT FULFILLMENT STATEMENT

This special report, submitted in partial fulfillment of Contract Nonr-686(00), summarizes and concludes the results of all full-scale testing of the ring-vortex generator at the U.S. Navy Mine Defense Laboratory, Panama City, Florida, under ONR sponsorship. The results of the continuing basic investigations will be the subject of future reports under this contract.

## I. INTRODUCTION

A. Work under Contract Nonr-686(00) was initiated on 1 December 1951, as a result of interest on the part of the Office of Naval Research in Aerojet's proposal to initiate a program of investigation into the feasibility of sweeping the pressure-magnetic mine by means of the radially expanding ring vortex. Basic interest in vortex motion for mine-sweeping purposes lies in the fact that motions of this type have the characteristic that relatively large energies and momenta can be concentrated in the motions of comparatively restricted volumes of water. These energies and momenta can be projected through the fluid with relatively small losses. Experimental results are presented for successful sweeping of pressure-magnetic mines by "tumbling" and creating semi-permanent underpressures caused by changes in the datum plane of the bottomed mines.

B. From the beginning of this program, a division of work was made. The basic investigation of the parameters for behavior of ring vortices was initiated and is continuing in an exhaustive study of the hydrodynamics involved. The major effort was expended in the use of basic data to design, develop, and test a ring-vortex generator for sweeping the pressure-magnetic mine. This report covers only the latter phase, the development of the sweep device, and as much of the basic data as is necessary for clarity. The report on the basic ring-vortex studies will be submitted upon completion of the investigations.

## II. SCOPE OF WORK

A. In accordance with Contract Nonr-686(00), the following work was to be performed:

Conduct research on pulsed-pressure-signal investigations. This work shall include, but shall not necessarily be limited to, fundamental studies primarily concerned with the design of an exit section for a ring-vortex generator, to obtain more efficient energy conversion to the vortex, and studies planned to provide information necessary for the prototype generator design.

B. On 1 December 1952, Amendment No. 1 to the basic contract modified and extended the work to be accomplished:

The contractor shall (1) conduct research on pulsed-pressure signals; (2) design and construct an experimental vortex-ring generator of approximately prototype size for sea tests and development work; and (3) concurrently with work required under (1) and (2), investigate the practical problems attending the use of such a device as a mine countermeasure, and attempt to provide solutions to these problems, in order that the device may be readily applied to naval uses. This work shall include, but not necessarily be limited to, the following:

1. Completion of the prototype design

2. Construction of the prototype

3. Mounting and testing of the prototype on a Navy-furnished vessel

4. Concurrently with prototype development, the investigation of effects caused by non-vertical projection of the vortex, by motion of the generator during projection of the vortex, by the nature of the bottom, etc., upon the efficacy of the ring vortex in mine sweeping.

## III. RESUME

A. A 36-in.-dia vortex generator was constructed for experimental testing in the Aerojet ring channel. This generator (see Figure 1) in its simplest configuration is that of a 36-in.-dia cylinder, with a heavy cover plate and an open bottom to which are attached test orifices of various shapes. An axial rod extends down to a pad in the channel bottom to prevent recoil while firing. Liquid fuel is introduced through the top to a vaporizing pan and mixed with air by a small fan. Two diesel-type spark plugs are actuated by a spark-coil ignition system. Compressed air is used to scavenge the chamber.

1. This scale-model vortex generator was suspended over the Aerojet ring channel and tests were conducted in fresh water, depth 10.5 ft. The ratio of combustion volume to total generator volume was controlled by raising and lowering the water level in the channel.

2. Instrumentation was set up to determine the pressure signature on the bottom and, by means of photography, the ring dimension and velocity. Pressure signatures were registered by a modified Statham P-5 pressure transducer and recorded with a Consolidated oscillograph.

3. Pressure signatures on the bottom of the ring channel indicated that it is not feasible to create an underpressure duration of 10 sec by means of induced velocities, although a pressure signature to trip an integrating-type mechanism can be duplicated by this method. Difficulties in maintaining a pressure range on the bottom, however, led to experiments wherein "tumbling" a mine and creating permanent underpressures by changes in datum plane were conducted.

B. For the "tumbling" experiments the channel bottom was covered to a depth of 10 in. by a layer of finely washed plaster sand. Experiments were conducted using a 1/4-scale model (with respect to dimensions) of the Mk 25 mine case in which the pressure transducer was mounted in place of an exploder mechanism. Pressure readings were recorded as in the previous tests. Figure 2 is taken from a group of non-consecutive frames from a 35-mm high-speed film of one of the tests. In this case the previously buried mine was uncovered and moved upward, resulting in the necessary pressure change. Figure 3 shows the action of the vortex on a mine model lying on top of the sand.

C. Model tests were scheduled in Long Beach Harbor using the same 36-in.-dia model generator and 1/4-scale mines. A total of 102 tests were made, 77 on a mud bottom and 25 on a hard sand bottom. Test results, even at depths of 50 ft, demonstrated the potential of the ring-vortex generator as a sweeping device and the design of a prototype sweep was initiated.

D. The prototype sweeping device was designed to be barge-mounted and towed, with all operations fully automatic and controlled from the tow vessel. Only the starting of all machinery was to be non-automatic. The designed sweep speed was 5 knots. A YC-type craft was requested as the flotation barge.

E. All machinery for the prototype was assembled at the Aerojet plant (see Figure 4) while the YC-704 was undergoing modifications at the Norfolk Naval Shipyard. Shipment of the machinery was made in October 1953, and the entire sweeping device was installed at the Norfolk Naval Shipyard. The completion date was 4 December 1953. The tow to the Panama City, Florida, area was completed on 22 December 1953.

F. During the design period of the prototype, model studies were continued.

1. A 1/18-scale vortex generator was installed on a miniature barge to verify recoil and damping computations. An 8-in.-dia vortex generator was mounted on the rotating boom facility to check the path of rings which were generated while the generator was translated horizontally at speeds up to 5 knots.

2. An 18-in.-dia generator was used to determine the best method of projecting a ring in a non-vertical direction while the main part of the generator was held vertical. It was found that the entire cylinder need not be tilted. The simplest method for $45^\circ$ projection was found to be that of cutting the vertical cylinder at $45^\circ$, and covering the elliptical end with a flat plate in which a circular orifice was cut. Vortices were projected horizontally by the simple method of attaching a $90^\circ$ elbow ahead of the orifice.

3. The prototype installation was designed for a vertical cylinder, with a $45^\circ$ exit section to be installed when vertical testing was completed.

G. The YC-704 was ballasted to 530 short tons before testing was initiated. Test firings were initiated in January 1954, with no apparent difficulties in either the structural system or the firing cycle. The maximum recoil amplitude of the YC was approximately 15 in., indicating a virtual mass far in excess of the actual mass of 530 tons.

1. Fifty-five tests were conducted while the sweeping device was moored in 45 ft of water over a soft mud bottom. Bottom instrumentation consisted of dummy Mk 25 and Mk 36 mines, with A-6 and A-8 firing mechanisms installed. The mechanisms were wired so that the magnetic, pressure, and firing circuits could be monitored at all times.

2. On 27 April 1954 the YC-704 was towed to an area 6 miles offshore in the Gulf of Mexico. Static tests were then initiated in 70 ft of water over a hard sand bottom. During the next 3 months a total of 117 tests were made in this position to determine the sweep path of a single vortex projected vertically downward. These tests verified the predicted sweep of a 55-ft-dia circular area. Information was gathered on comparative sweep effectiveness in different sea conditions, and under varying chamber pressures. Basically, these tests were conducted as a prelude to the underway tests using a 45°-aft ring projection.

H. The vertical cylinder was removed from the YC-704 and modified for 45° projection. New air-intake valves with positive timing controls were installed, and two additional 100-kw generators were installed for fully automatic cycling operations.

I. A 15-mine field (see Figure 5) was laid in 90 ft of water for underway tests. The field was 50 ft wide by 100 ft long, and towing tests were conducted with the vortex generator in automatic cycling at various frequency rates. Seventy-two test runs were made over the field. The tumbling of the mines crowded them together in a smaller area, and in several instances tore the mines loose from their instrument cables. After the first six tests, data analysis became difficult owing to the uncertainty of mine locations within the field. Data reduction indicated a 50% sweep probability with a sweep width approaching 100 ft.

J. A system of static tests was set up for verification of this swept path, which was nearly double that measured previously. The static tests were conducted in 98 ft of water, using a system described in Figure 6. The sweep path measured in these tests was a 60-ft-wide path. The differences between underway and static test patterns are enough to warrant further tests under tow.

K. Acoustic output tests were conducted as a fill-in program while the pressure field was being laid. These tests indicated an output of considerable magnitude in the 3- to 600-cps range. Further development of the acoustic mine-sweeping possibilities is indicated. The output in this entire frequency range was greater than 140 db at 6 ft.

## IV. CONCLUSIONS

A. The ring-vortex method of sweeping the combination pressure-magnetic mine is undoubtedly feasible. Although the sweep probability does not approach 100%, the necessity for repetitious sweeping due to "ship count" mechanisms decreases the significance of this shortcoming.

B. The ring-vortex sweep, with its "action at a distance" technique, is a safe way to dispose of mines without loss of equipment or personnel. No operating personnel are required on the sweeping device, since all operations, except starting the power plant, are automatic.

C. The low cost of the sweeping device lends itself to mass production to meet the need for sweeping hundreds of channels at a cost which will not exceed the enemy's cost of laying mines.

D. The same device can be used to sweep acoustic as well as pressure-magnetic mines, using only a different exit section for aiming the ring. This becomes increasingly important as the possibility of a 3-component mine - acoustic-pressure-magnetic - becomes more real. The addition of another vortex-generating cylinder for horizontal projection as an acoustic sweep would add no more machinery, nor require more power, than a single cylinder.

E. The ring-vortex sweep can be operated by the average seaman without lengthy special training, can be towed by any sweep vessel of over 600 hp, and can be readily moved from area to area. No complicated logistic supply is involved since the fuel used is gasoline.

F. The operation of the ring-vortex sweep is not hazardous to operating personnel who have a basic knowledge of liquid fuels.

G. With the proper flotation craft, designed especially for the purpose, the ring-vortex sweep could be helicopter-towed for maximum safety and greater sweeping speed.

## V. DESCRIPTION OF WORK

A. A 36-in.-dia ring-vortex generator was constructed for experimental purposes. Figure 1 shows the first generator in place in the Aerojet ring channel. The vortex generator consists of a 36-in.-dia, 44-in.-long cylinder, a cover plate fitted with a fuel injector and ignition plugs, and some type of orifice through which the water must pass. In the first model the fuel - gasoline or paint thinner - was dropped into a heated vaporizing pan. Mixing was accomplished by blowing compressed air into the combustion volume or by a fan inside the chamber. An axial rod extended down from the generator lid through the orifice to the bottom of the ring channel, where a hold-down plate had been placed.

1. Tests were conducted in 10.5 ft of water. Combustion space was varied by raising and lowering the water level in the channel. The object of the model tests was primarily to investigate the effects of variation in the generator orifice. The instrumentation consisted of a pressure transducer on the channel bottom, and underwater cameras. The pressure transducer was placed at various distances from the ring axis to determine the pressure field created by an expanding ring vortex. Many orifice configurations were used in an attempt to slow the ring in its vertical descent, and therefore its radial spreading velocity. The majority of the

tests were conducted with converging orifices and flat-plate orifices. It became apparent that the strongest vortex could be produced with a sharp-edged, flat-plate orifice. Starting with an 18-in.-dia flat-plate orifice, and increasing the orifice diameter revealed that the strongest ring could be produced with a 30-in.-dia orifice.

2. The criterion used in evaluating these tests was the record of underpressures produced. No test gave the desired underpressure of 2 in. of water for 10 sec. Assuming, for scaling purposes, that durations would increase directly with generator diameter, the prototype would require a diameter of 40 ft. Since the mines of the A-6 and A-8 type are not integrating mechanisms, and the duration of underpressure must be greater than 10 sec regardless of the intensity of underpressure, this method of producing the required signal was abandoned.

3. Difficulty was encountered in keeping the pressure range on the bottom. Even when weighted down with a 50-lb weight, the pressure transducer was lifted and thrown by the expanding ring. This "tumbling" effect, it was believed, could be used to advantage in sweeping the pressure-magnetic mine. The passage of the ring over any object on the bottom would cause that object to be raised off the bottom. As the object was lifted off the bottom it would be caught by the vortex and tumbled. This new line of endeavor was then pursued as the basic method of sweeping mines through the use of a ring vortex.

B. In order that sweeping conditions might be more closely investigated, a 10-in. layer of sand was spread on the bottom of the channel and a scale-model Mk 25 mine was fabricated. Tests were conducted with the model fully buried, half-buried, and lying on top of the sand.

1. Two distinct and effective sweep actions occurred. The first was that a layer of sand was stripped off the fully buried mines and replaced by less-dense water. This effectively reduced the hydrostatic pressure on any part of the buried mines. Second, the "tumbling" action

tore mines out of the sand and carried them to a new location, with an excellent probability that the mine would come to rest at a slightly different depth. Figure 3, taken from a 35-mm high-speed motion picture, shows the action of the vortex on a mine lying on top of the sand.

2. The fully buried mine models appeared to be the most readily swept. Mines lying on top of the sand were the most difficult to sweep, since their final position of rest is also on top of the sand, and the required 2-in. underpressure is a matter of chance and the topography of the bottom.

C. The successful tumbling of the 1/4-scale mine models by the 36-in.-dia vortex generator provided a basis for scaling a prototype. Accordingly, the full-size generator was designed as a cylinder 12 ft in diameter and 22 ft long. The combustion volume for the gas-air mixture would be approximately 500 cu ft.

D. Prior to the initiation of design of the prototype, the Office of Naval Research made provisions for testing the 36-in.-dia model vortex generator in deep water. The generator was mounted on the side of a YFN-type barge and tested at various depths and over various bottom conditions in the Long Beach Harbor area. Quarter-scale mines containing pressure transducers were lowered to the bottom under the generator and tests conducted in depths of 22 to 51 ft over a mud bottom and 30 to 49 ft over a hard sand bottom. These tests were conducted with the YFN anchored or moored, and exact mine-sweeping conditions could not be duplicated. After several tests in one location the bottom became pock-marked and results deteriorated. However, since the swept path of the model generator was small, there was no attempt to sweep while under way. In each new location the first test successfully caused an underpressure in excess of 2 in. of water for durations exceeding 10 sec. Six tests in which the mine models were allowed 15 to 90 min "settling" time showed adequate signatures for sweeping. There was no apparent decrease in vortex strength to depths of 51 ft, and no decrease in the sweep area, which appeared to be a circular area with a diameter 4-1/2 times the ring diameter. The tests on a hard sand bottom were less successful, as was anticipated from the results of the tests at Aerojet.

E. An 8-in.-dia generator was constructed for the purpose of testing while the generator was being translated horizontally at speeds up to 5 knots. The generator was assembled on the rotating boom in the Aerojet ring channel and fired as it passed the underwater windows where cameras were installed. The vortex was projected in three positions: vertical, 30°, and 45° from the vertical. Analysis of the pictorial evidence showed the ring to be unaffected by movement of the generator at speeds up to 3 knots. The ring descends vertically, when the generator is mounted vertically, from the point of generation; and it does not have any observable velocity component in the direction of generator movement. However, at speeds of 4 to 5 knots the ring axis appears to tilt in such a manner as to cause the ring to approach the bottom in a slightly curved path. This tilt is always in the direction to increase the distance from the generator to the point of impact on the bottom. For example, with the generator tilted 30° aft from the vertical, at a speed of 5 knots, the vortex travels a short distance in a path which is coincident with the centerline of the generator at the time the ring is formed. After about 4 dia of travel, the ring axis gradually tilts and the ring travels in a line 35° from the vertical. With the generator vertical and at a forward speed of 5 knots, the tilt angle has been observed to be 13°. In each case the final angle of tilt was a direct function of the velocity of generator motion and an inverse function of the angle between the axis of the generator and the vertical.

F. An 8-in.-dia model vortex generator was mounted in a model barge corresponding to a 300-ton barge for the prototype. This assembly was designed to provide a means of verifying the computations of recoil velocity and amplitude. Figure 7 shows the method of photographing used to determine the average recoil and counter-recoil that occurred. It was apparent that unless the virtual mass of the prototype flotation craft was considerably greater than that of the actual mass, a recoil amplitude in excess of 3 ft could be expected. Because of the high damping of the system, only one cycle of the barge oscillation is of importance. These tests in general verified the possibility of using a YC or YFT flotation barge for the prototype sweeping device.

G. The problem of tilting the entire generating device to project the ring vortex aft in order to avoid detonating mines under the sweep device remained to be solved. Various methods of tilting the generator were attempted. The non-symmetrical combustion chamber, which is produced by tilting the cylinder, gave unusual effects and made installation of auxiliary machinery difficult. After considerable experimentation with tilted cylinders, various elbow-type exit sections were used. Finally, in an attempt to simplify the entire installation, a vertical cylinder was cut off at an angle of 45°, the elliptical bottom then being covered by a flat plate in which a circular hole had been cut. This type of 45°-projection device appeared to be as effective as a 45° elbow, provided the diameter of the flat-plate orifice was decreased to about 85% that of the orifice for vertical projection. The stagnation areas surrounding the exit section appeared to effectively redirect the water flow and cause a vortex to travel in a direction perpendicular to the orifice plate (see Figure 8).

H. Experimentation with the fuel-injection system for the prototype generator was conducted in an 18-in.-dia model. The basic fuel to be used was gasoline, since a simple logistics system is necessary in areas where mines are to be swept. A high-pressure system is somewhat undesirable in that the shock of detonating mines is likely to cause severe stresses in pipelines and tanks. It was therefore decided to use a combination of pressure and preheating to insure atomization. Experiments with degrees of preheating and various pressures indicated that regular gasoline, heated to 200°F, will vaporize readily upon injection, and pressures of 100 psig are sufficient to cover the area inside the cylinder with a fine spray. Higher pressures can be used to increase the flow rate of the fuel injectors if desired.

I. The prototype vortex-generator design was completed; the method of attachment to the flotation craft was decided in conference with representatives of the Norfolk Naval Shipyard, and a suggested plan for modification of a YC-type barge was sent to the Chief of the Bureau of Ships. The Norfolk Naval Shipyard was directed by the Bureau of Ships to review the plans and make changes where necessary. The Chief of Naval Operations directed that the YC-704 be used as the flotation craft on a loan basis, with the provision that upon completion of tests, the YC-704 would be returned, in its original condition, to the Chief of Naval Operations.

1. The structural modifications performed on the YC-704 consisted of three major items:

a. The cutting of a 16-ft-dia hole, from top to bottom, in the center of the YC

b. The fabrication and installation of a heavy truss system to strengthen the YC as insurance against breakup under repeated recoil of the vortex generator

c. The installation of internal strength members centering around the 16-ft-dia cylinder to be fitted into the cut hole, tying the entire structure together.

2. The external framework (see Figures 9 and 10) consists of four longitudinal built-up, wide-flange sections, connected by four transverse sections and 16 diagonals. These sections were fabricated in the shops and "let in" to the YC bottom where they were welded solidly to the internal structural beams of the YC. The external framework was then connected to the internal framework by welding a 16-ft-dia cylinder to both and welding all structural members to the skin of the YC. The longitudinal and transverse

beams extend 5 ft below the bottom of the YC. An additional recoil buffer, extending 8 ft below the external structural framework, was installed to permit the firing of the vortex cylinder when modified to fire ring vortices aft at 45° and 90° from the vertical. All structural modifications were performed with the YC inverted on the dock.

J. The vortex-generation system as presently installed in the YC-704 consists of a 12-ft-dia cylinder with semi-elliptical head and a 10-ft-dia flat-plate exit section or orifice. The cylinder is 20 ft long. Burnt gases are exhausted, through a 24-in. butterfly valve located in the center of the cylinder head, by two centrifugal exhausters, each rated at 6500 cfm at a vacuum of 3.92 in. of mercury. Air influx is through two 16-in. butterfly valves leading to four 12-in. inlets arranged tangentially 3.5 ft below the exhaust outlet. The air is drawn in, as the burnt gases are exhausted, with a cyclonic swirl which permits complete scavenging, in approximately 3 sec, of the entire 600-cu-ft combustion volume. Gasoline fuel, 130 octane rating, is injected through 12 fog-jet injectors controlled by four electric valves actuated by the timing system. Fuel injection at 100 psig is completed in 0.25 sec immediately after the scavenging is completed. Ignition is by four Bendix-Scintilla TFN ignition units, the combined capacity of which is 48 sparks/sec with 0.075-in. spark gaps. The electrodes are adjustable in height from 12 to 36 in. from the top of the cylinder head. Best performance has been achieved with the electrodes protruding 30 in. into the combustion space. The timing of all units is controlled by cam-actuated switches driven by a single variable-speed electric motor. Electrical power for the vortex-generation system is provided by three 100-kw, 440-v ac, diesel-driven generators. Two generators are directly connected through the distribution board to the exhausters, each generator driving one exhauster. All other machinery is driven by the third generator. Parallel operation was avoided because of the variable loads on the exhausters. Exhauster loading changes from 30 kw when the exhaust valve is closed to 104 kw when the exhaust valve is open.

1. The vortex-generating cylinder was installed while the YC-704 was in the inverted position. Mounting flanges were drilled and 56 2-in. bolts, in double shear arrangement, were inserted to hold the generator in place. The YC-704, weighing 215 short tons, was then lifted into the water and righted for installation of the actuating machinery. Installation was completed on 4 December 1953 and the YC was towed to Panama City, Florida, arriving on 22 December 1953. The U. S. Navy Mine Countermeasures Station supplied and mounted one 100-kw diesel-driven, 440-v ac generator as a partial power supply. It was planned to have 350 kw power available from a tow vessel, but since no underway operations were scheduled for the first 6 months, only sufficient electrical power was needed to actuate the machinery for single-shot testing. Figures 11 and 12 show details of the installations prior to the initiation of tests.

2. The Mine Countermeasures Station made ready dummy Mk 25 and Mk 36 mines for test purposes. These mines, using A-6 and A-8 firing mechanisms respectively, were equipped with a monitoring system so that the two magnetic switches, the pressure switch, and the firing switch could be continuously monitored and their actions recorded. A four-conductor demolition cable was attached to each mine and the cables led to strip-chart recorders on the YC.

K. The vortex generator was first fired on 18 January 1954. Initial firings were made with rich fuel mixtures intended to keep chamber pressures low and gradually shake down the equipment. Chamber pressures were gradually increased to 45 psig, with no apparent weakness in either the generating equipment or the flotation craft. The air-intake valves appeared to be opening during pressure buildup. Successive tests showed that the swing check valves were not adequate, and during the next four months various schemes were used to improve the action of those valves. The chamber pressures were apparently reduced by the opening of these valves, since locking the valves shut increased chamber pressures to 55 psig. New positively controlled butterfly valves were ordered and installed prior to the deep-water tests. The recoil of the flotation barge, ballasted to 530 short tons, was measured as 15 in. with a chamber pressure of 55 psig. This was approximately 60% of that computed.

1. A total of 55 tests were made against mine mechanisms during the first month of operation. These mines were laid from the YC-704 at a depth of 45 ft. On 17 of these tests, mines received a pressure signal sufficient to hold the pressure switch open for a duration exceeding 10 sec. This first series of tests was primarily a shakedown period, and the results were not as good as those on later tests. Primarily, the poor results were due to two causes: (1) the generator was being fired with low chamber pressures owing to poor valving; (2) the mine mechanisms used were defective. Six of the 10 mines used were found to be defective in some way after being returned. This latter condition has persisted throughout the test period, and probably is responsible for many otherwise unexplainable results. Divers, who charted mine positions before and after each shot, reported mine movements which did not show magnetic signature. Divers reported the crater formed by the vortex as 35 to 40 ft in dia, with depth varying from 3 to 8 ft for a single shot.

2. The ring-vortex sweep was next moored in 70 ft of water, over a hard sand bottom. Mines were laid from the cranes installed on the YC-704, and divers were on hand to chart the mine location before and after each shot. A total of 117 tests were made, with the number of mines on the bottom varying from one to four. Sea conditions varied from flat calm to 6-ft swells. Pressure transducers were mounted on the mines, on the same end and concentric with the pressure diaphragm. These were mounted as a check on the pressure-circuit monitoring system, and to determine the degree of mine movement. The greatest vertical movement recorded was 14.8 in. upward from the original level and 18.8 in. downward.

3. Raw data showed 78 adequate pressure signatures out of a possible 366 signatures. However, 14 mines had been placed outside the

predicted 55-ft-dia sweep area, 48 mines were tested during Condition 2 seas when swells were breaking up the pressure signatures, 30 mechanisms were known to be defective, and 22 mechanisms were fired at with rings of inferior strength. Of the remaining 233, 74 pressure signatures were received for a sweep probability of 31.8% in calm or Condition 1 seas.

L. Upon completion of the vertical-projection tests at the 70-ft depth, the sweeping device was brought to the dock for installation of the 45°-projection device. The cylinder was removed from the YC-704, using a YSD floating crane for the lift. The cylinder was laid horizontally on rollers and a 6-ft section removed from the bottom. A 15° bend was fabricated by cutting the cylinder at 7-1/2°, rotating the cutoff section 180°, and rewelding. The 30° exit section was then welded in place, giving a total bend in the cylinder of 45°. This method of installation was chosen so that the revised cylinder could be re-installed from the top of the YC and would not require modification of the YC or dry-docking.

1. The recoil arrangement which was designed for the vertical cylinder then had to be modified for the new cylinder in order to take up the forward thrust of the chamber firing at 45°. Instead of modifying the recoil plate, which was 13 ft under water, a series of built-up buffers were welded to the cylinder in such a manner that when the cylinder was dropped into place, these buffers would meet the recoil plate and transfer the thrust to the plate.

2. At the time of cylinder re-installation, all preparations for underway tests in automatic cycling were made. Two additional 100-kw diesel-driven generators were installed to furnish power. The three 100-kw generators were wired into the distribution board in such a manner as to obviate parallel operation. That is, one generator was to furnish power to the starboard 6500-cfm exhauster, one generator was to furnish power to the port 6500-cfm exhauster, and the third was to furnish all auxiliary power, such as the 100-cfm air compressor, 40-kw fuel heater, timing motor, water pump, electric winch, firing circuit, fuel injection, exhaust and

intake valves, and utility circuits. While this system is such that failure of one generator causes failure of the entire system, it was believed that the problems of employing three generators in parallel in a system where the load changes from 100 kw with the exhaust valve shut to 300 kw with the exhaust valve open, and this change occurs in 1/2 sec, would be both costly and undependable. Fortunately, no generator failure has occurred to date.

3. The air-intake swing-check valves were removed, and each pair of 12-in. inlets was manifolded to a 16-in. butterfly valve, pneumatically controlled. Additional timing circuits were added to control the intake valves with the exhaust valve.

4. Operation of the entire system in automatic cycling was initiated with a 10-sec cycle. Chamber pressures of 45 psig were obtained consistently on a 10-sec cycle, with no decrease in consecutive shots, indicating satisfactory scavenging. Attempts to use both exhausters simultaneously, however, with a consequent flow of 13,000 cu ft of air per minute, showed that considerable water was being pulled into the exhaust line. No damage occurred, but a decision was made to avoid subjecting the exhausters, rotating at 3500 rpm, to slugs of solid water being pulled through the 24-in. exhaust line. The inspection plate of the cylinder was opened and the cycle initiated, without fuel injection, for observation of the flow in the cylinder. As the exhaust valve opened, the air entering the cylinder tangentially caused a water-spout to appear in the center, and water was pulled into the exhaust line in the top of the cylinder. It was noted that if only one intake valve was opened, flow through the 20-in. inspection port was increased, and since the air flow through this port was vertically downward, the water-spout was effectively reduced. Accordingly, the one intake manifold was blanked off, and the valve installed over the inspection port. Tests were then continued with both exhausters used simultaneously.

M. A mine field consisting of 15 Mk 35, Mod 3 mines was laid in 90 ft of water for the underway tests using the 45°-aft ring projection. This mine field was laid in a pattern (see Figure 5) in such a manner that data could be analyzed from the standpoint of sweep probability as well as sweep width. To each mine was attached an instrumentation cable, led to an instrument vessel, the YNG-27. By ranging from the YNG to the outer marker buoy, and to the sweep device as it passed over the range, it was possible to determine the track of the sweeping device in relation to the field.

1. A total of 72 passes were made over the field, with the vortex generator in automatic cycling, with the sweep speed ranging from 2 to 5 knots and the cycling time ranging from 16 to 8 sec. In addition, several passes were made over the field with the sweep inoperative so as to determine the magnetic and pressure signatures of the YC-704 craft.

2. The data recorded were consistent only for the first six passes. Examination by divers after completion of the tests showed that the expanding ring-vortex had thrown all the mines into a small area in the center of the field, and that instrumentation cables had been torn off and mines damaged by collision with other mines. Fourteen of the mines were found in an area 40 x 20 ft, with the remaining mine approximately 100 ft southward.

3. Since the mine field was completely disrupted, only the first six passes were used for analysis with regard to swept path. The results of all 72 passes were used, however, in computing the sweep probability, since no mines were found outside the original field except one whose instrument cable had been torn off and for which no data had been recorded.

4. In computing the overall sweep probability, it was assumed that (a) all mines were within the sweep path on each run (this, it is known, is a false though conservative assumption, but since the field shifted continually under the action of the vortex, no other assumption can be made);

(b) a pressure signature which held the pressure switch open for a duration exceeding 10 sec was adequate for sweeping; and (c) the mine field remained relatively intact for the first six runs. Thus a total of 1080 mines were used for the tests, i.e., 72 passes times 15 mines per pass. From this a total of 286 mines must be subtracted due to mine failures. These failures were those whose cables were torn off, or whose pressure switches stuck in the open position after being swept. Tests 7, 8, 9, and 58 were single-shot tests for the determination of the swept path of a single vortex, and the corresponding mines are subtracted from the total. Of the remaining 744 possible sweeps, 296 mines received pressure signatures of sufficient duration and intensity for sweeping - a sweep probability of 39.8%. Had it been possible to accurately determine the position of each mine before each run, assumption (a) above would not have been accepted, and the sweep probability would have been considerably higher. In analyzing the first test runs, the same assumptions were made. Of the 73 possible, 37 mines received adequate pressure signatures for a sweep percentage of 50.7%. The sweep path, as determined from the first six tests, was computed as 100 ft in width. This is nearly double the 55-ft width realized with vertical ring projection.

5. Towing speeds greater than 4 knots indicated that the non-operating sweeping device and barge had a pressure signature of sufficient strength to sweep pressure mines in a path approximately 20 ft wide. Consequently, the majority of tests were made at speeds below 4 knots. The magnetic signature in water 90 ft deep appeared to be 25 to 30 ft in width. These signatures, it is believed, could be avoided in a flotation craft specially designed to carry the vortex sweep.

N. In an attempt to verify the swept path of the ring-vortex sweep with 45° projection, a test procedure was adopted as shown in Figure 6. Ten Mk 36 mines were used as planned, but Mine 1 failed completely before tests could be started, and in Mine 3 the pressure switch failed to operate. Because the YNG was scheduled to be overhauled, there was not time to replace the two inoperative mines.

1. Tests were begun with distance "A" at 107 ft, and were continued until the distance between ships was only 10 ft. Sea conditions prevented any further decrease with safety in this separation distance. During the test period, in which 39 individual test shots were fired, various mines failed until only three remained in operating condition when the tests were halted.

2. Figure 13 shows the test results as plotted from the data taken. The static tests show the area to be approximately 60 x 60 ft square. Although no data could be gathered in the 0- to 10-ft section of the path, the high percentage of sweep in the 10- to 20-ft area, plus the experience in plotting the sweep path in model studies, assured good sweep probability in that area. The data, as taken from Figure 13, neglecting data outside the 60 x 60-ft square, show, briefly:

| | | |
|---|---|---|
| Total number of mines in 60 x 60-ft square | = | 161 |
| Number of adequate pressure signals | = | 91 |
| Sweep percentage | = | 56.5 |

3. In actual sweeping operations there would be some overlap of patterns to assure adequate coverage. Assuming a tow speed of 5 knots, an 8-sec cycle would overlap the 50- to 60-ft distance with a second sweep. For probability of sweep, then, it is permissible to compute only the 0- to 50-ft distance. Figure 13 shows:

| | | |
|---|---|---|
| Total number of mines in 60 x 50-ft area | = | 130 |
| Number of adequate pressure signals | = | 79 |
| Sweep percentage | = | 60.7 (neglecting any effect of twice sweeping the overlap area) |

O. No positive reasons are apparent for the great difference in width of sweep between underway and static tests. Several factors are enumerated here as probable causes, though none are considered alone as being adequate to produce the large variation:

1. No data are at hand yet concerning the optimum angle at which the vortex should be projected aft. It is entirely possible that at $55^{\circ}$ from the vertical the swept path is greater than at $45^{\circ}$. Since model tests showed that the vortex axis shifts when the generating cylinder i translated (see paragraph E, above), this increase in angle could influence the swept path.

2. Errors in navigation, range-taking, and misalignment of the mine field when first laid could have given false information on the underway tests.

3. The outermost mines in the field used for underway testing may have been very sensitive, therefore giving true readings for those particular mines, but not for average mines.

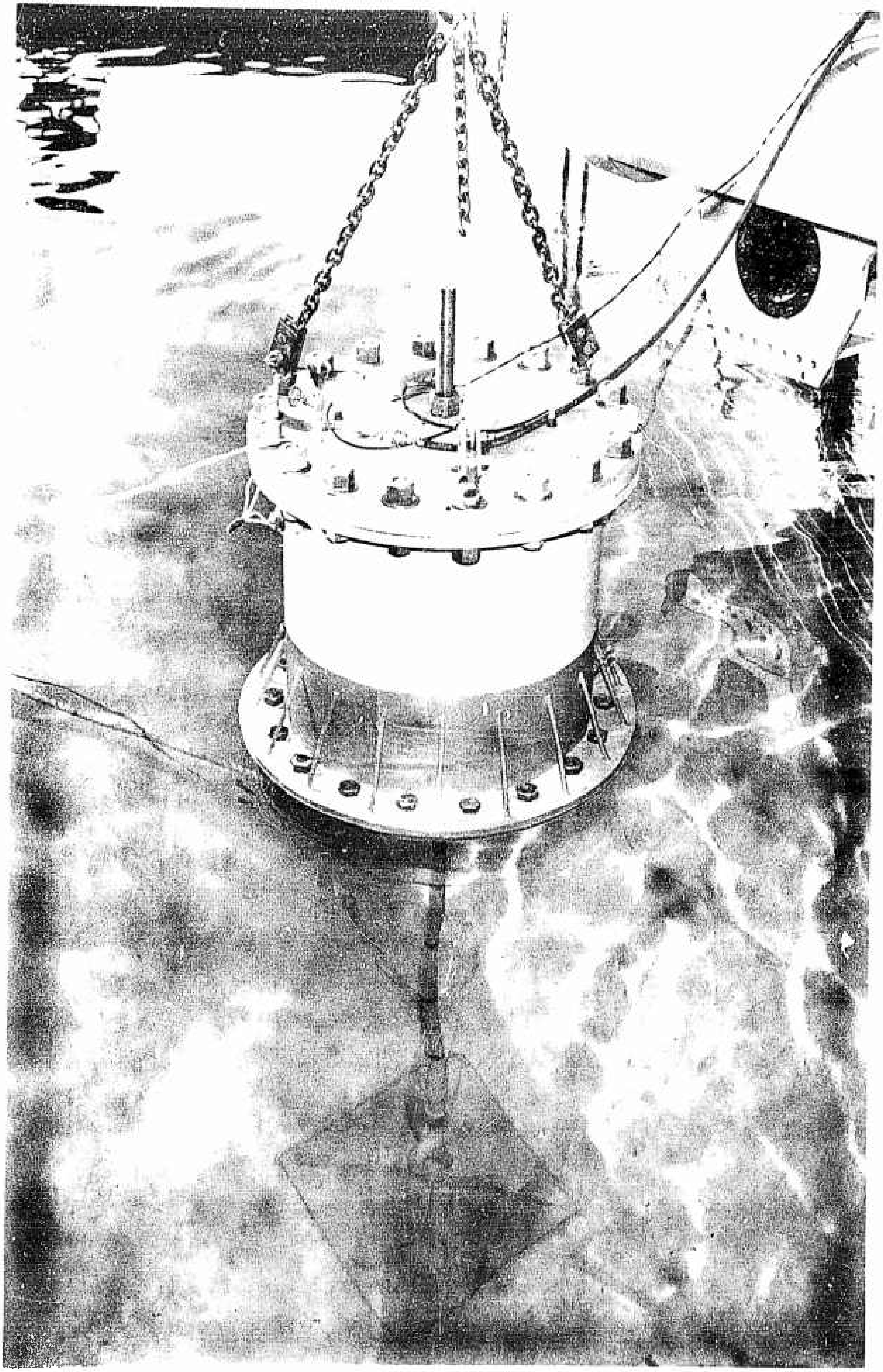
4. No instrumentation system will give entirely accurate results if the instruments themselves are erratic. The entire full-scale test program has been plagued with erratic stock-piled mine mechanisms which do not give accurate information under all circumstances.

5. Yaw of the sweeping device while operating over the mine field would cause an increased width of sweep. No large yaws were recorded, but could have occurred and been unnoticed by operating personnel.

P. Acoustic tests were performed in 45 ft of water, using the $45^{\circ}$ ring projection. Hydrophones were located at 20 and 30 ft from the ring axis, and recordings made by Ampex recorder. The results of analysis are shown in the table below, and in Figure 14. It is evident that, if the ring vortex were projected horizontally, the acoustic signal so generated would be of sufficient strength, and cover a wide enough band of frequencies, for mine-sweeping purposes. Since the 12-ft ring could be projected a distance of half a mile, and since the forward speed of the ring is approximately 15 knots, modulation of the signal would be produced by the ring travel if a sweeper were to project ring vortices off each beam to sweep a one-mile path.

ACOUSTIC DATA

| Test No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Frequency cps | Output, db, 20 ft from Source | | | | | | | | | |
| 3-6 | Not Recorded | 134 | 138 | Not Recorded | 133 | 138 | 140 | 134 | 130.5 | 140 |
| 4-8 | | 140 | 147 | | 142 | 147 | 147 | 141 | 139 | 144 |
| 6-12 | | 143 | 152 | | 148 | 148.5 | 148 | 145 | 143 | 146 |
| 8-16 | | 144.5 | 154 | | 152 | 152 | 150 | 151 | 147.5 | 147 |
| 15-30 | | 143 | 153 | | 150.5 | 151 | 147 | 152.5 | 144 | 147 |
| 20-40 | | 142.5 | 148 | | 147 | 149 | 149 | 147 | 143 | 144 |
| 30-60 | | 140.5 | 147 | | 143 | 147 | 146 | 148 | 144 | 142.5 |
| 40-80 | | 138 | 145 | | 142 | 143 | 143 | 145 | 142.5 | 142 |
| 60-120 | | 134 | 138 | | 141 | 140 | 137 | 143 | 137 | 142 |
| 80-160 | | 130 | 132 | | 138 | 138 | 134 | 137.5 | 132 | 137 |
| 150-300 | | 126 | 134 | | 137 | 137 | 129.5 | 132.5 | 129.5 | 134 |
| 200-400 | | 125 | 129 | | 136 | 133 | 128 | 131 | 128 | 130 |
| 300-600 | | 126 | 137 | | 134 | 132 | 127 | 130 | 126 | 132.5 |



Vortex Generator in Aerojet Ring Channel

Figure 1

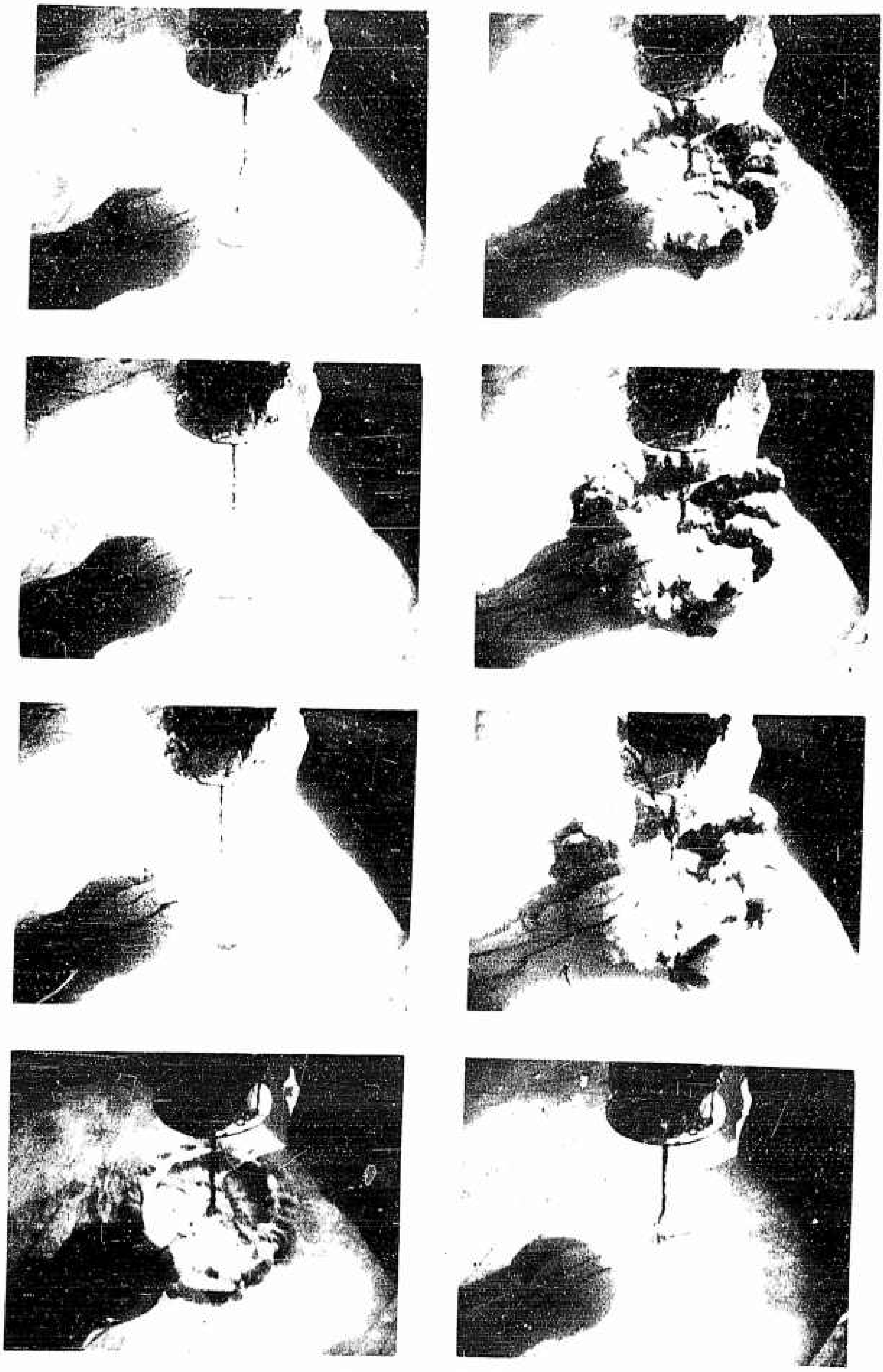
S E C R E T

S E C R E T

Vortex Ring Sweeping Fully Buried Mine

Figure 2

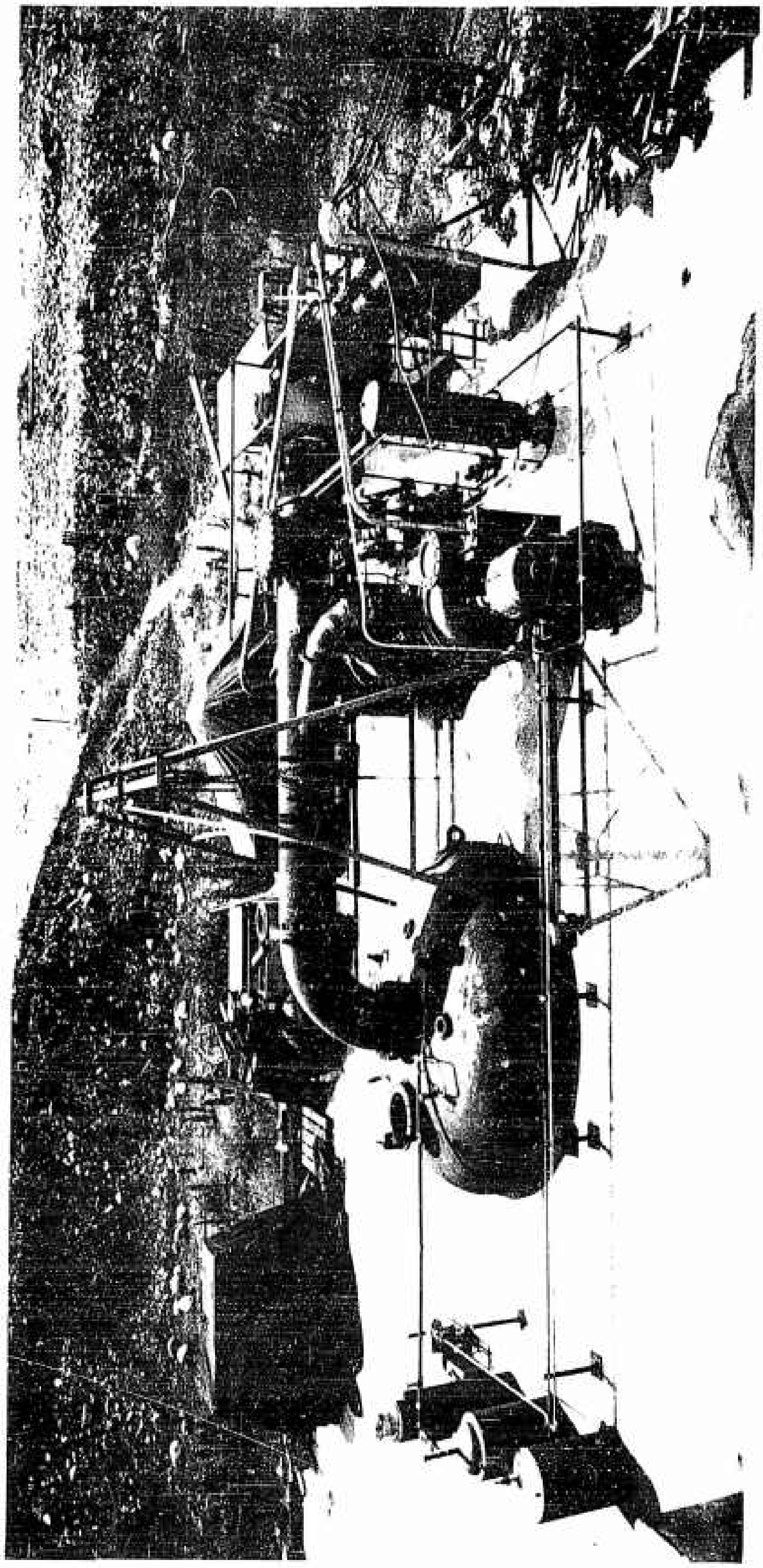
SECRET



SECRET

Vortex Ring Sweeping Mine Lying on Top of Sand

Figure 3



Vortex-Ring Generator, Assembled

0753-307

Figure 4

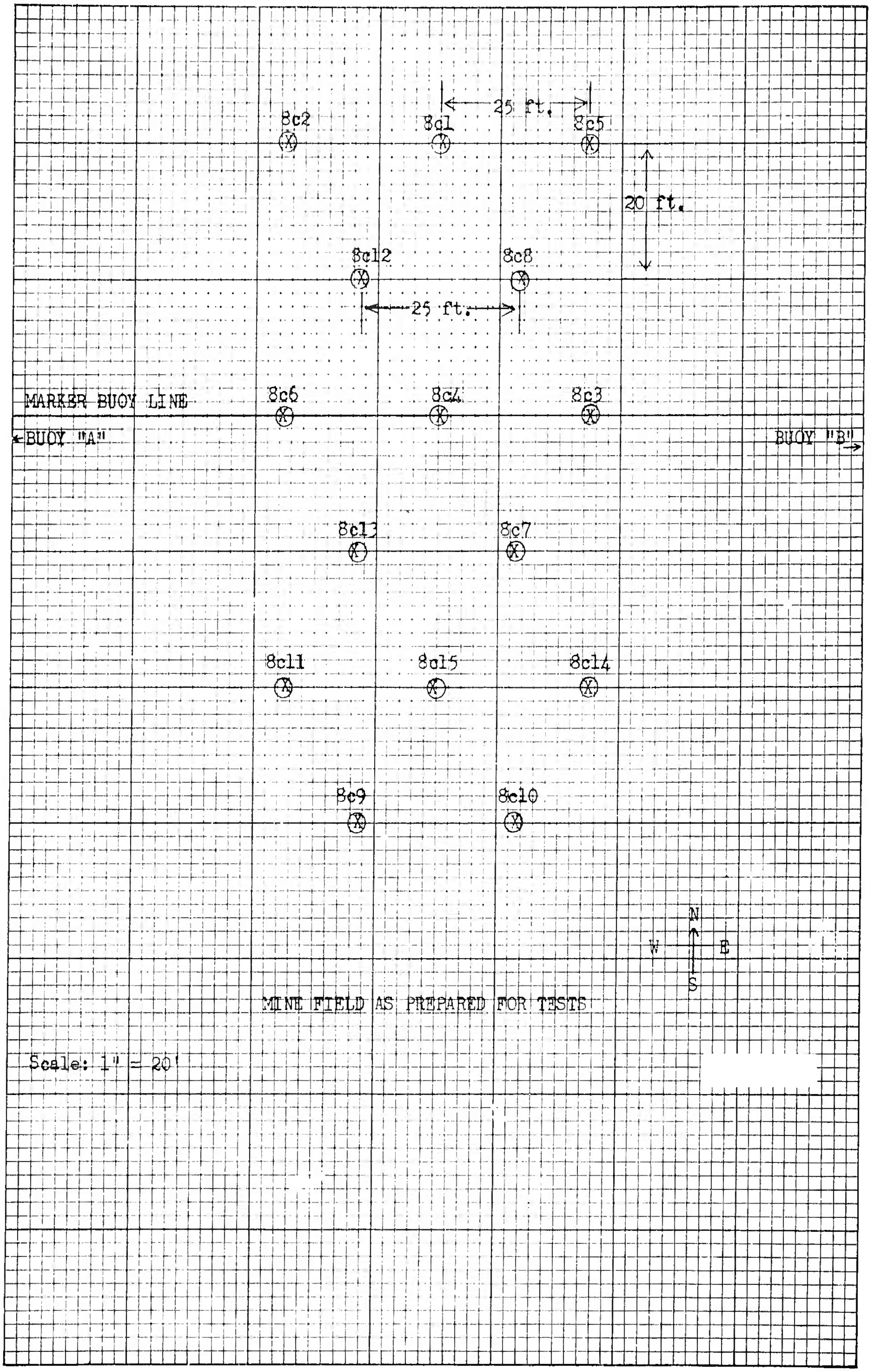
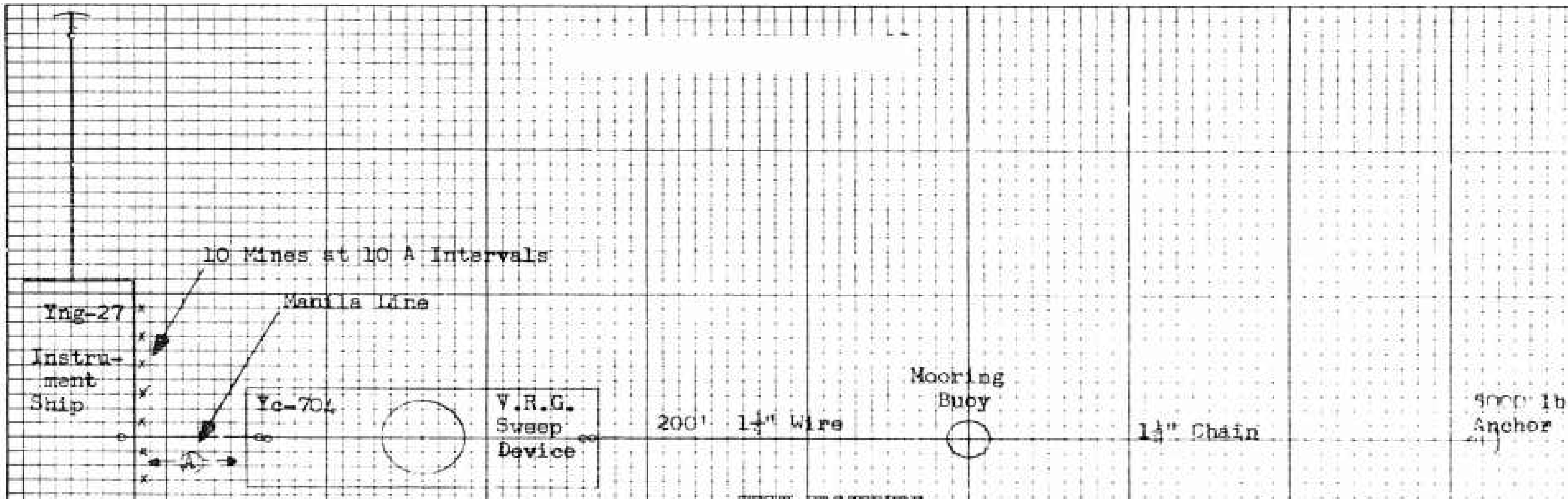

25 ft.
8c2
8c1
8c5
20 ft.
8c12
8c8
25 ft.
MARKER BUOY LINE
8c6
8c4
8c3
BUOY "A"
BUOY "B"
8c13
8c7
8c11
8c15
8c14
8c9
8c10
N
W
E
S
MINE FIELD AS PREPARED FOR TESTS
Scale: 1" = 20'

Figure 5




TEST PROCEDURE

Step 1. Moor Yc-704 so that space (A) is 100 ft. (155 ft. from V.S. Gen. to Mine Field.)

Step 2. Raise mines off bottom. When all raised and mooring is stable, drop mines to bottom. Allow time for mines to equalize.

Step 3. When mines are ready, make final preparations for test shot.

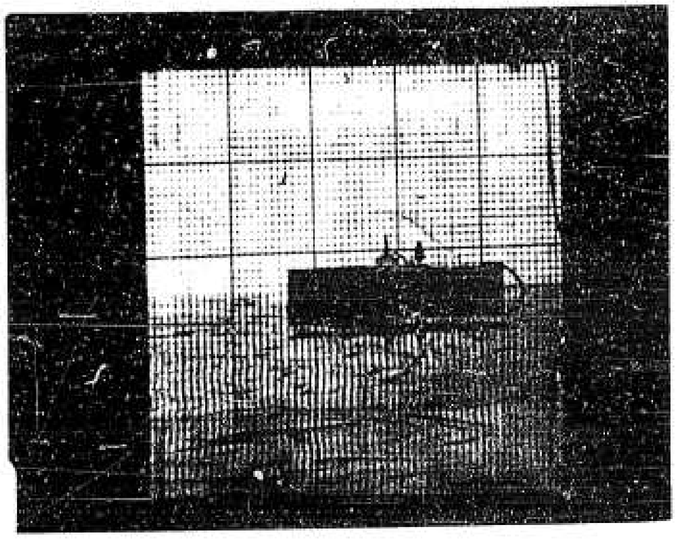
Step 4. Slack the manila line between Yc-704 and Yng and fire. (Manila line must be slacked to prevent breakage as the Yc lunges forward.)

Step 5. Re-moor, with space (A) 90 ft. and repeat. Decrease space (A) in 10 ft. increments, with 3 shots at each position.

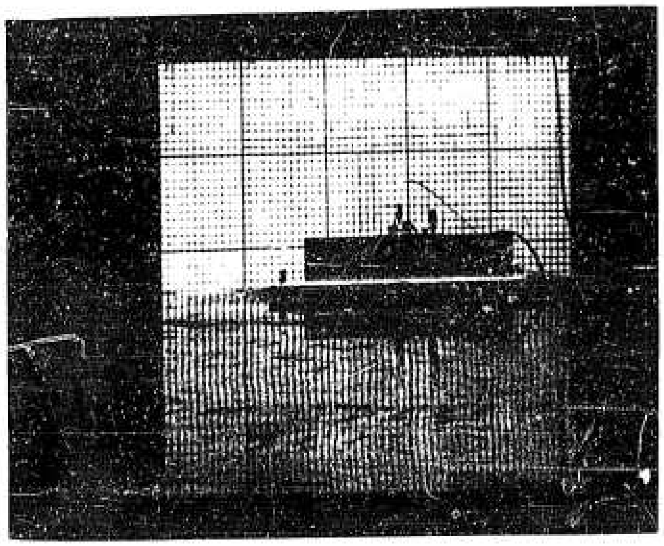
NOTE: When space (A) is reduced to zero, slack Yng mooring cables so that mines can be laid when the Yng is pulled out of position by pulling on the Yc mooring cable. When mines are laid, slack Yc mooring wire and take up on Yng mooring.

PROPOSED TEST METHOD

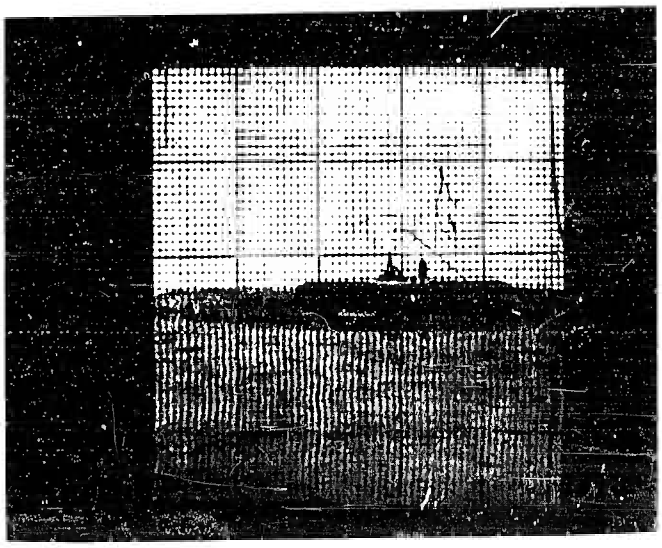
Figure 6



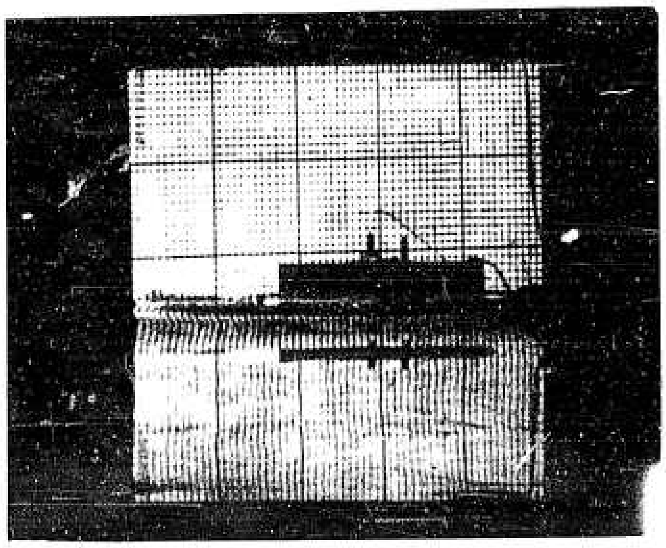
(a) Barge Position Before Firing



(b) Maximum Recoil Height



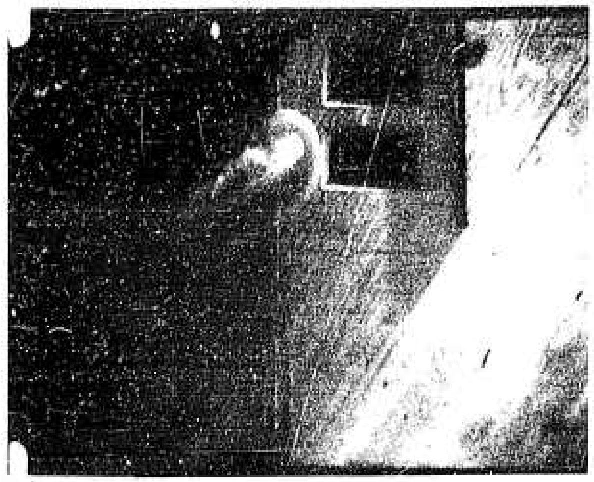
(c) Maximum Counter Recoil



(d) Maximum Height, Second Cycle of Oscillation

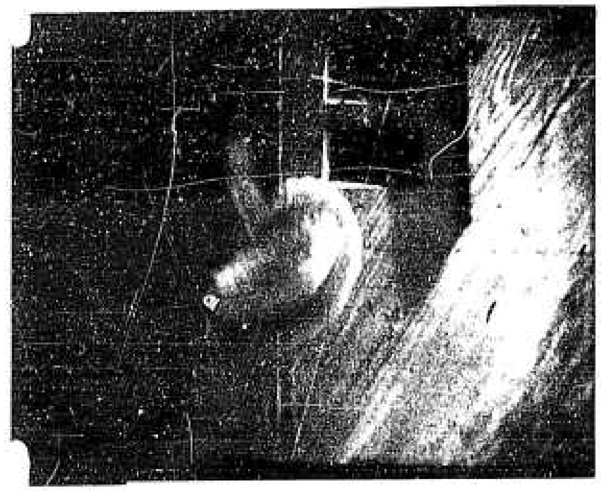
Typical Recoil Cycle, Model of 300-Ton Barge, with Vortex Generator Vertical

Figure 7



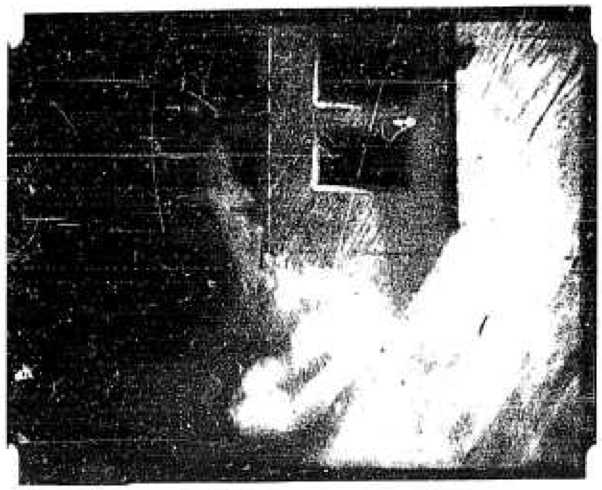
0653-041

a



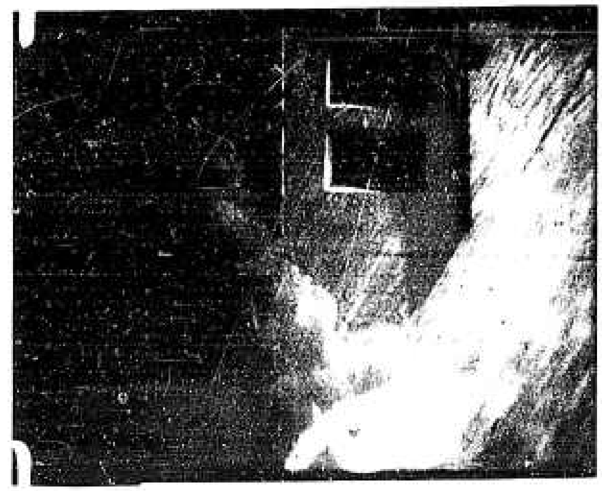
[illegible]

b



0653-039

c

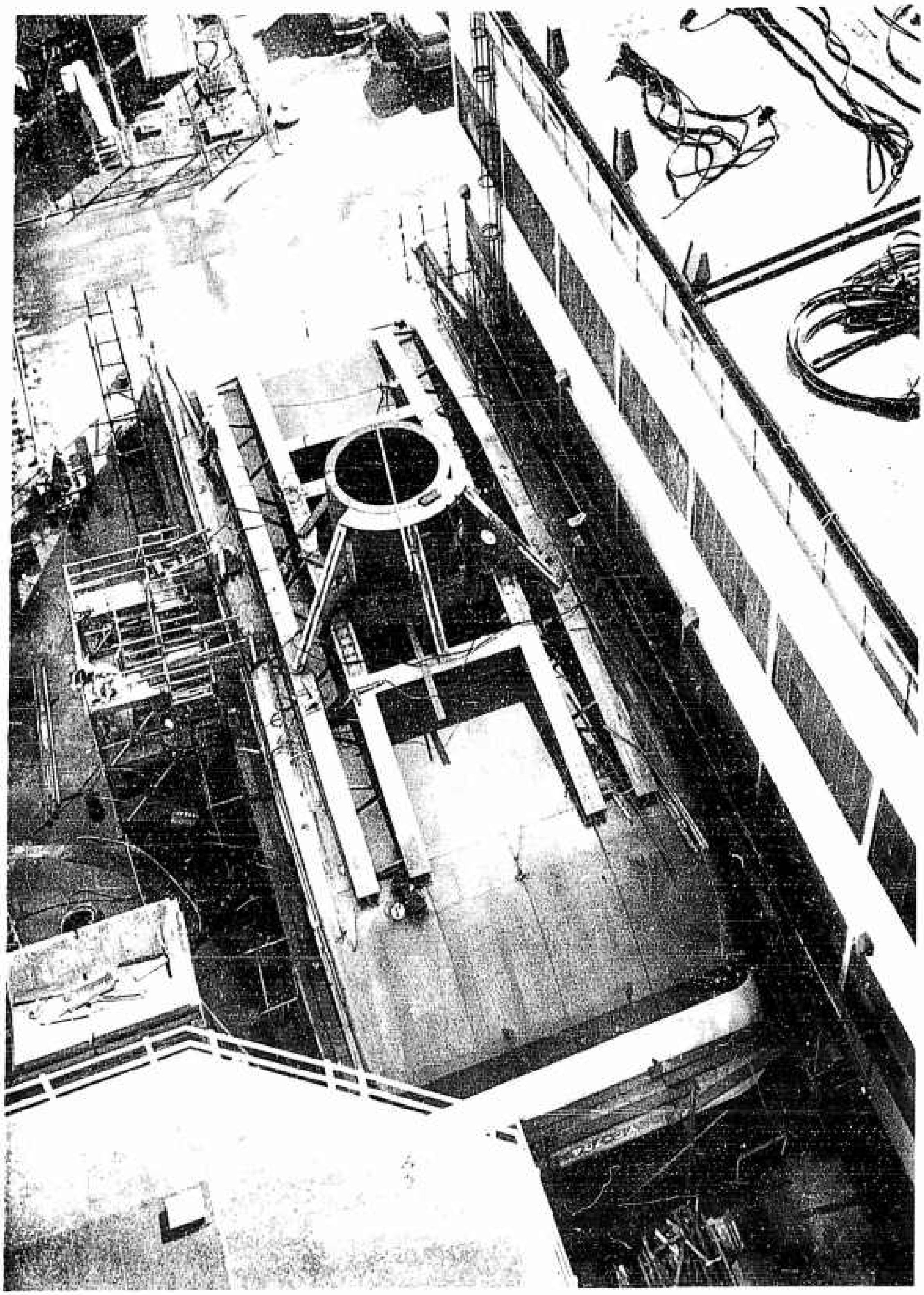


0653-038

d

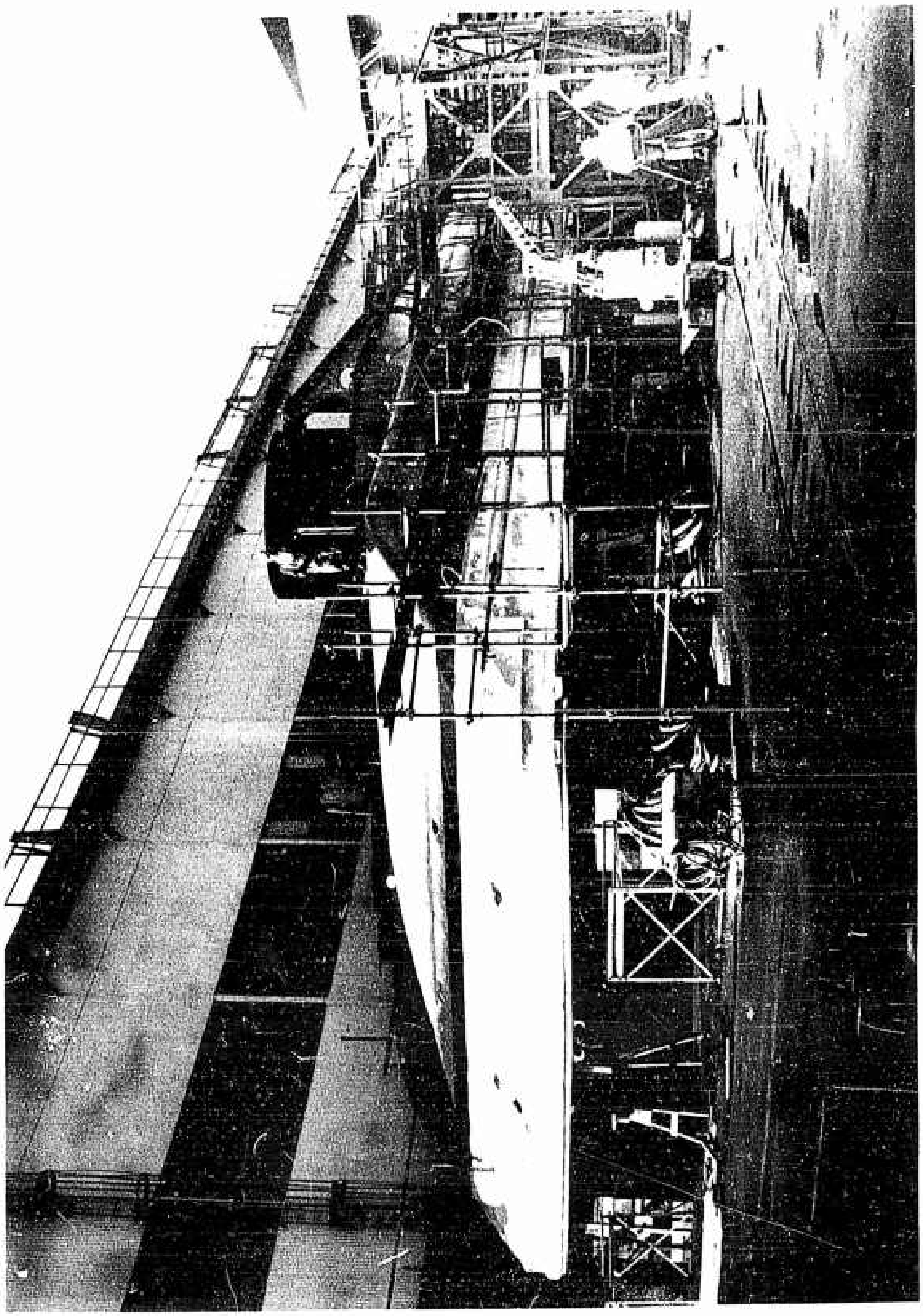
Four Non-consecutive Frames of Movie Film Showing Vortex Formation
Generating Cylinder Filled with Colored Fluid, 45° Exit Section

Figure 8

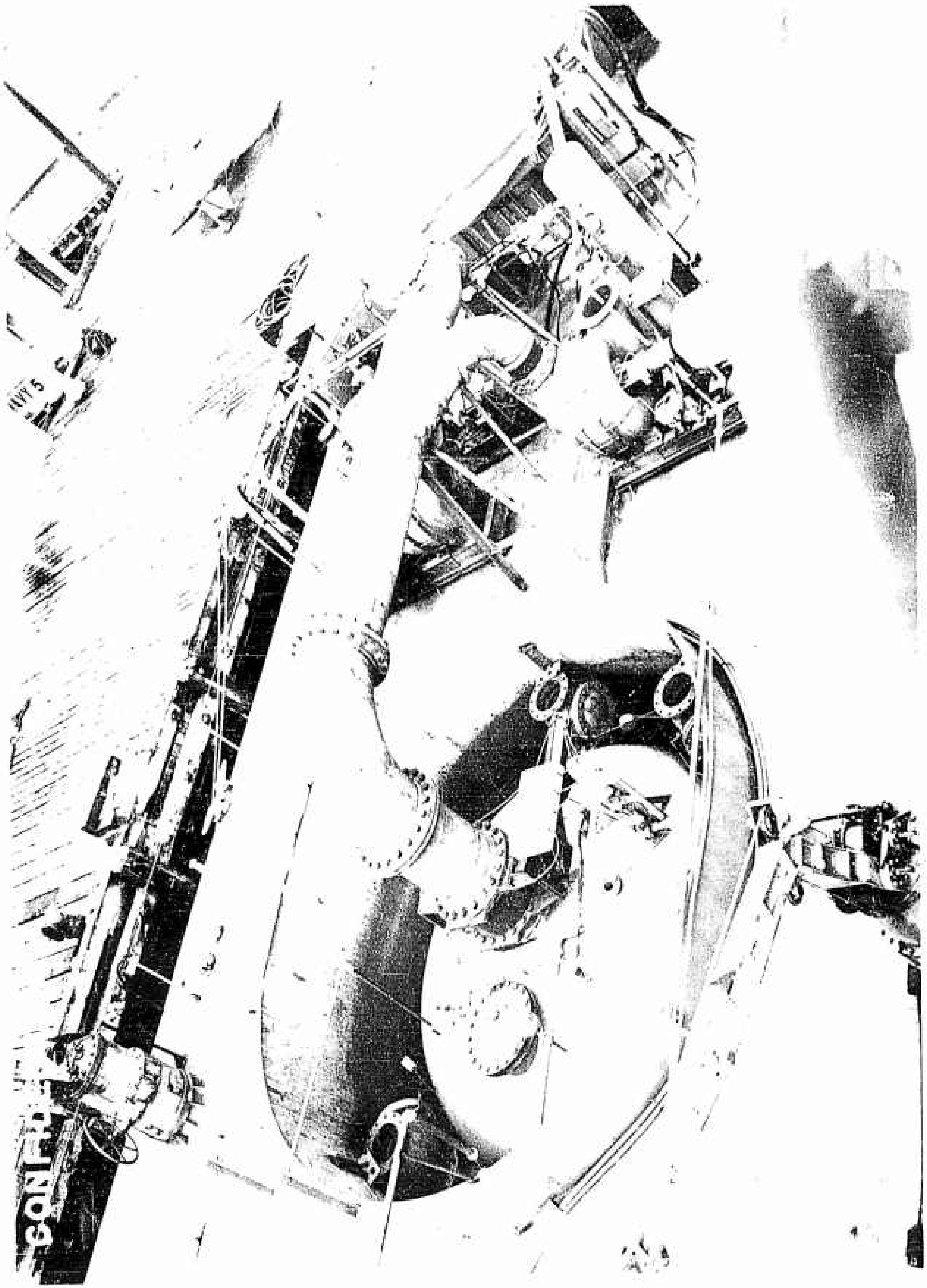


YC-704, Inverted, with Vortex Generator Installed

Figure 9

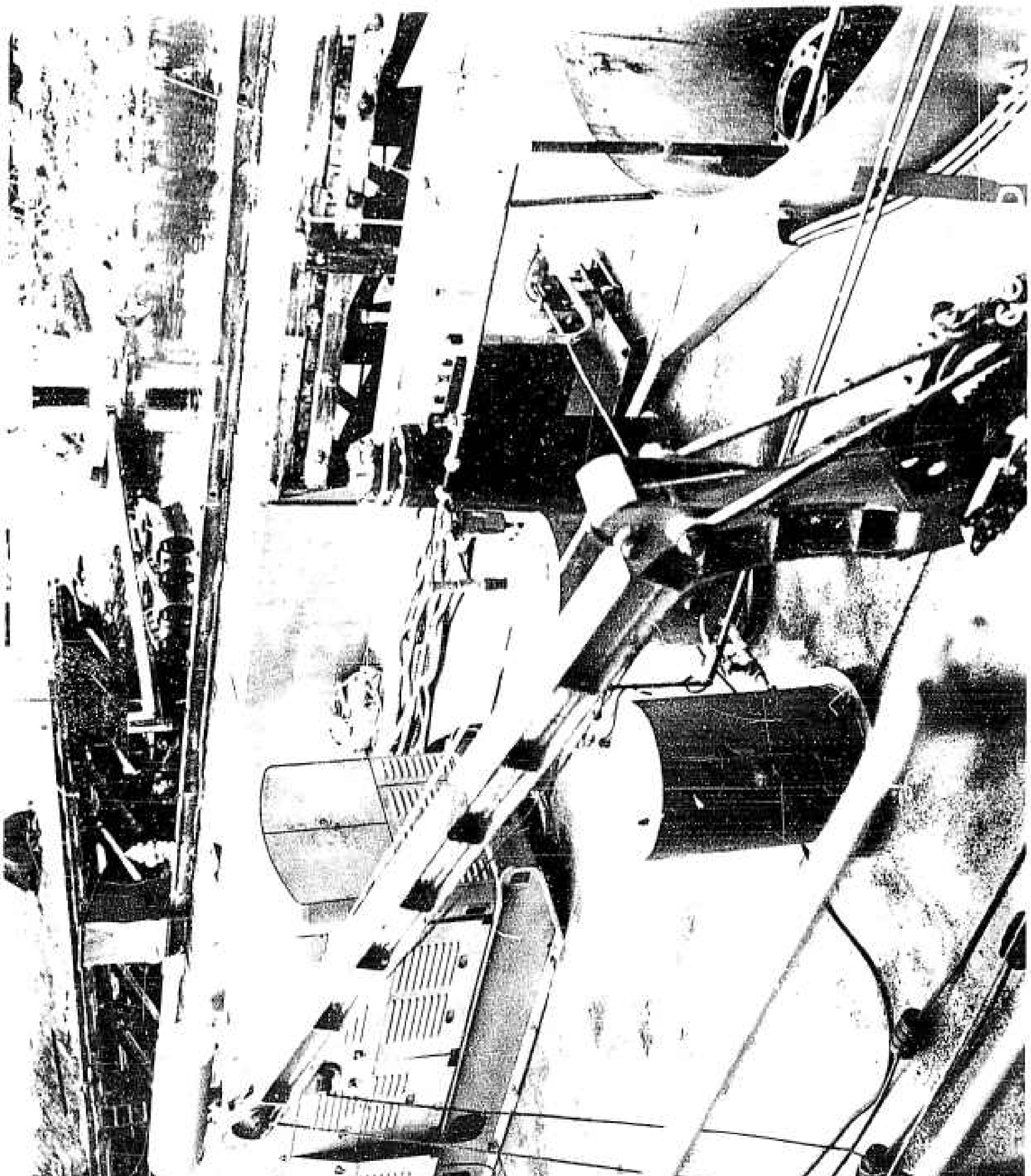


YC-704 Undergoing Structural Modification



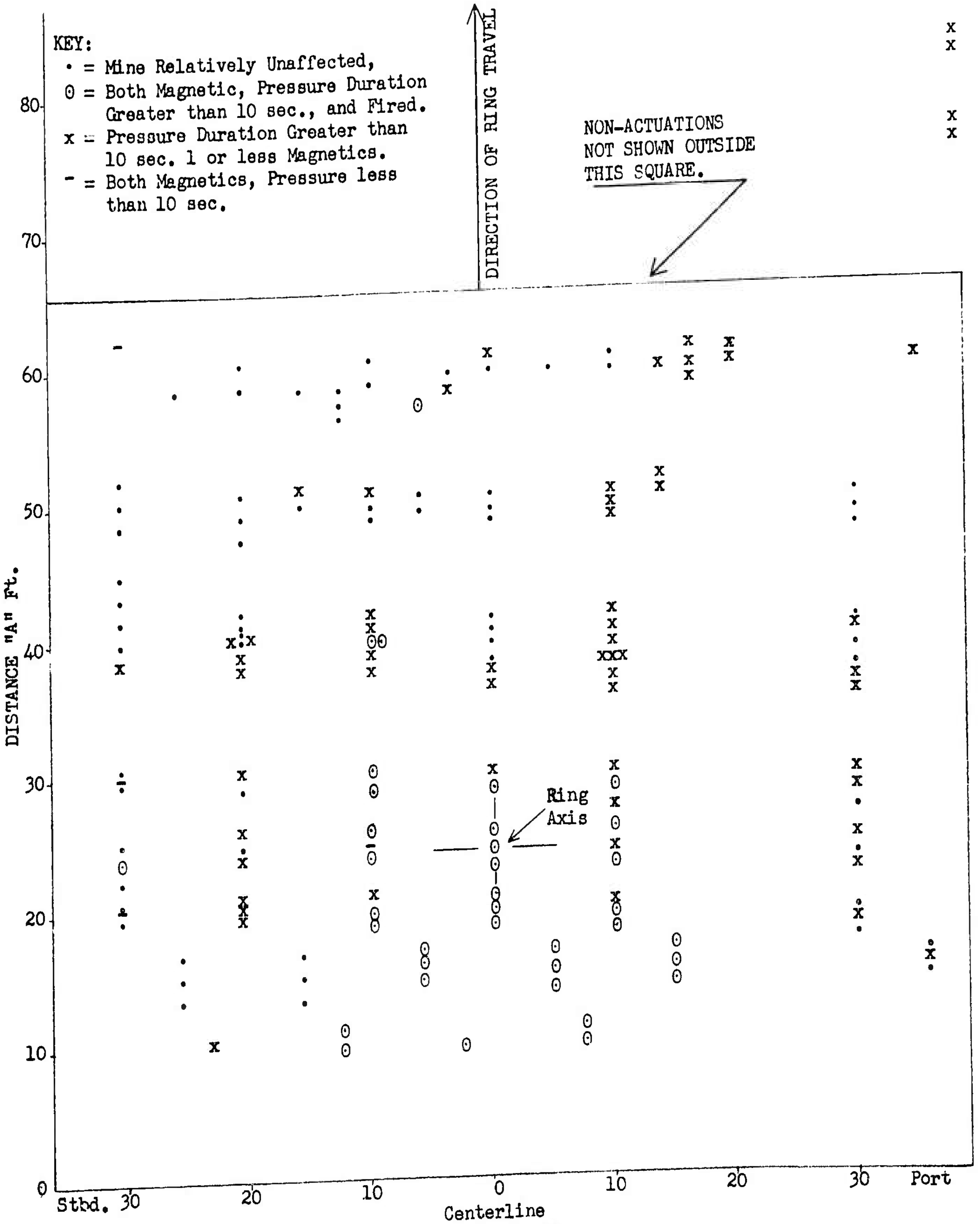
Vortex Generator Installed in YC-704

Figure 11



Fuel Supply and 100-kw Generator Installed in YC-704

Figure 12




Sweep Width, ft.

MOORED TESTS, 45° ELBOW

Figure 13

E.S/E.W. C 4327

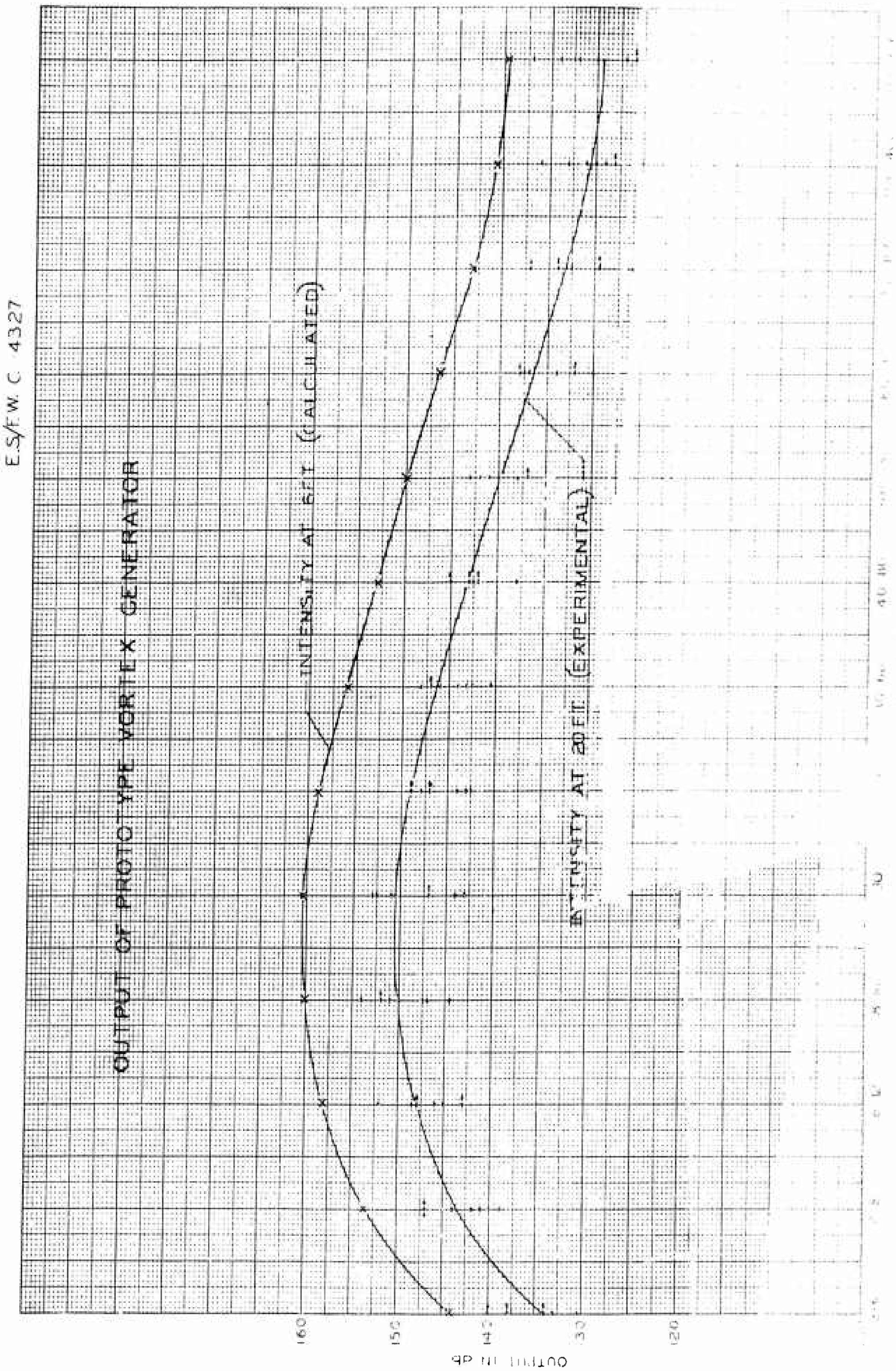



Figure 14